The Cryosphere Discuss.,
doi:10.5194/tc-2016-19-AC1, 2016

The Cryosphere
Discussions

Interactive comment on "Brief Communication: Evidence of a developing Polynya off Commonwealth Bay, East Antarctica, triggered by grounding of iceberg" *by* C. J. Fogwill et al.

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Received and published: 4 June 2016

We thank each of the reviewers for their detailed reviews, and in light of their comments and suggestions have updated our manuscript as outlined in the following paragraphs. The reviewers raise two key issues. Firstly, they request more details of the model, and question suitability of 2009 climatology in driving the pre-calving simulation. Secondly, they raise questions over the apparent contradiction between our observations and model simulations. In our resubmission we address these points directly, with an expanded model description and climatological analysis (within the main text, and the supplementary information), and perform further analysis of the trends in circulation and sea ice production off Commonwealth Bay in the model simulations that support

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our assertion that a polynya has developed in the lee of iceberg B09B. In addition, we have reformatted the figures within the main body of the text in line with the reviewer's comments, and include additional figures in the supplementary files to address the reviewer's specific comments as outlined in the paragraphs below. Again, we wish to thanks the reviewers for their detailed comments that have substantially strengthened this Brief Communication in the Cryosphere.

1 The title is somewhat misleading. A polynya is defined as a region of lower sea ice concentration than what would otherwise be expected given the climate of that region. We can easily see that this is a new polynya from satellite imagery/other data. What this paper presents is the oceanographic consequences of this new polynya. As such, I suggest changing the title to reflect this focus.

Response: We understand the reviewers point here, and as such have reworded the title to, "Impacts of a developing polynya off Commonwealth Bay, East Antarctica, triggered by grounding of iceberg B09B"

2 I have an issue with the recurring reference to the "grounding of B09B". B09B has significantly grounded twice (at least!) since its calving from the Ross Ice Shelf in 1987. As such, reference to the "grounding B09B" is ambiguous. Perhaps change to "recent re-grounding" or similar.

Response: We recognise the reviewer's point regarding the long-history and multiple groundings of B090B since its calving in 1987, but here we are discussing the instance of grounding in Commonwealth Bay post Mertz Glacier Tongue calving in 2010, as outlined in the title, abstract and Page 2, Line 15 of the manuscript. There are many other manuscripts (many of which we include within the 20 references available) that detail the history and events prior to and during the Mertz Glacier calving in 2010, but this is not the purpose of this Brief Communication for the Cryosphere, which aims to understand the observations from 2013 from Commonwealth Bay through our model analysis.

3 Line 1: “triggered by the impact” – this hasn’t been proven. There is an argument that the calving of the MGT was precipitated by the movement of B09B which altered the current configuration, thus calving without an impact. This was outlined in detail by Mayet et al., 2013 (JGR Oceans). This important work on the MGT calving is not cited.

Response: We acknowledge this point, and have changed the wording in Line 1 to, ‘. . .precipitated by the movement. . .”. We agree that Mayet et al., 2013 provides an important discussion of the hydrological events during the MGT calving event, but are unfortunately limited as to the number of references we can include.

4 P2, L5, other places: The point is made that local changes in the icescape can influence AABW formation, but this ignores the fact that B09B was produced thousands of km away (i.e., not only local, but remote icescape changes can have large impacts).

Response: We remove the word ‘local’ from line 6, page 2, and ‘regional’ from line 8, page 3, to acknowledge that changes in the icescape away from Adelie Land may also have an affect in this region.

5 P2, L11-13: There is more to the existence of the CB polynya than just these factors, i.e., the presence of the MGT, B09B, many smaller grounded icebergs around which fast ice forms, all located upstream of the CB polynya.

Response: We thank the reviewer for this comment – we are here talking about the historically present Mertz polynya as opposed to the newly created one in the lee of B09B off Commonwealth Bay, and have changed the wording of Page 2, Lines 13 and 14 to clarify this.

6 P2, L13-15: The text before and after the semicolon is a non sequitur. Also “the sea ice” is ambiguous.

Response: We have changed the wording of this sentence to make its meaning more obvious.

7 P3, L1-2: As with P2, L5: There is more to the westward flow blocking than just the

MGT. See the description provided by Massom et al., 2003 (JGR).

Response: We have changed 'blocked' to 'reduced' to reflect this point.

8 P3, L11-13: This sentence could do with a re-write. Also, mention that while the MGT calving cycle may be cyclic, the re-grounding of B09B in CB is likely to be a "spanner in the works".

Response: We thank the reviewer for this comment, and have restructured the sentence accordingly, and highlighted that we are talking about the impacts of MGT calving on AABW formation being cyclical, as opposed to the appearance of 'megabergs' such as B09B.

9 P3, L16: For completeness, you need to mention the contribution of Cape Darnley polynya to AABW – see paper by Ohshima et al., 2013 (Nature Geo).

Response: We thank the reviewer for suggesting this and in our updated manuscript we add the AABW sites at Cape Darnley and off Vincennes Bay.

10 P4, section 2.1: There is absolutely no mention of which month observations were conducted. This seriously adds to confusion in the interpretation of figures.

Response: We thank the reviewer for spotting this omission, and have added the month (December 2013) accordingly.

11 P4, L24: Tamura et al.'s heat and salt flux data are based on thin ice thickness data, not sea ice concentration data.

Response: We acknowledge this, and have updated this section of the manuscript and include further details both in the text and in the supplement.

12 P5, L1: I see a major issue with forcing the model using 2009's heat and salt flux data. As shown in Tamura and Williams et al. (2012), 2009 was a strongly anomalous year for sea ice production in the Mertz Glacier polynya. In fact, assuming you didn't use the MODIS fast ice mask (which there is no mention of in this manuscript),

2009 had the highest sea ice production of all years observed. The use of 2009 may have been able to be justified if the pre-calving observations were also conducted in 2009, but they weren't (they were conducted in 2008). While not explicitly stated, it appears that the authors have simply chosen 2009 because it was the year before calving occurred. This appears to be a very poor choice, and has probably influenced the conclusions drawn from the modeling component here. Unless I'm missing something here, I think it would have been much more sensible to force the pre-calving model run using either a more normal year for sea ice production, or a sea ice production climatology based on all of Tamura's years of observation. The choice of 2012 for post-calving seems fine, however. Perhaps the choice of 2009 could be justified by performing a sensitivity analysis? I'm not sure how a sensitivity analysis could be done without rerunning the whole model though.

Response: The choice of the year 2009 for the PRE simulation forcing was made after analysing the monthly heat and salt fluxes averaged over the Mertz Glacier Polynya (MGP) area for the period 1992 to 2013 from Tamura et al., (2016; Figure 1). The period from 2007 to 2009 was identified as a constant sustained period with a winter average (May to September inclusive) of about -164 W m-2, while the average over the pre-calving period (1992-2009) is of -159$\pm$17 W m-2. Similarly, the salt fluxes averaged for 2007-2009 is of about 0.82 kg m-2, while the averaged for 1992 to 2009 is of 0.82$\pm$0.1 0.82 kg m-2. As a result, 2007 to 2009 is considered as being a representative period for the pre-calving MGP region. Ultimately 2009, the year closest to the calving, was chosen as the main purpose of the simulations in this study is to illustrate the general ocean conditions related to a stable ice geometry pre- and post-calving. Also, a single year forcing was preferable to a pre-calving climatology, when compared to a single year forcing for the post-calving simulation, that is restricted to one year due to data availability. In the post-calving scenario, 2012 was chosen in consideration of the fast ice and its representation of permanent features between 2010 and 2012 (A. Fraser personal communication). In summary, the results from these simulations are not restricted to the year chosen for the forcing, they can be compared with other years of similar salt and heat flux intensity as seen from Figure 1. We have added this detail in full to the supplementary information, due to length restrictions of the main body text.

13 Section 2.2: The description of the model setup/domain is completely inadequate. What is the resolution? Latitudinal and longitudinal extents? Grid setup? Bathymetry used? What hope does someone have of reproducing your results without this fundamental information? Or are you tasking the text "similar to Cougnon et al., 2013" with providing this information? How similar, exactly? In this case, you need to be more explicit here. And how was the fast ice treated in the model? What was its horizontal extent? Tamura and Williams et al. (2012) highlighted the importance of using accurate fast ice in polynya studies, but the fast ice implementation in the model is not even mentioned here. Was the "dagger" fast ice forming around grounded icebergs to the north of the pre-calving MGT included? This acts to extend the MG polynya (both preand post-calving). So many unanswered questions related to the model domain.

Response: We have now fully outlined the model description in the supplementary material to cover all these points as outlined below: The model used here is based on the Rutgers version of the Regional Ocean Modeling System (ROMS) (Shchepetkin and McWilliams, 2005) that includes ocean/ice shelf and frazil ice thermo-dynamics (Galton-Fenzi et al., 2012; Dinniman et al., 2003). The horizontal and vertical grid is the same than presented in Cougnon (2016). Without a dynamic sea ice model, the fine-scale polynya activity is resolved by forcing the surface of the model with monthly heat and salt from Tamura et al. (2016) data set that is based on sea ice concentration estimated with the Tamura et al. (2007) algorithm. This algorithm estimates thin ice thickness using Special Sensor Microwave Imager (SSM/I) observations and the European Centre for Medium-Range Weather Forecast Re-Analysis data (ERA-Interim). Water masses formed on the continental shelf in the model are controlled by the variability of the air/sea forcing as well as by the glacial melt water released from the local ice shelves. The model has been set up to compare the ocean and basal ice shelf melting changes post-calving compared with other years of similar heat and salt fuxes intensity within the MGP region. The year 2009 and 2012 are chosen for the pre- and the post-calving air/sea forcing simulations respectively, after analysing the monthly heat and salt fluxes averaged over the Mertz polynyna area for the period 1992 to 2013 (Figure S3). The year 2009 is representative to an average to strong sea ice production year in terms of heat and salt fluxes and 2012 was chosen in consideration of the fast ice and its representation of permanent features between 2010 and 2012 (A. Fraser personal communication). Fast ice is parameterised as in Cougnon et al. (2013) and Cougnon (2016), using an updated version of Fraser et al. (2012). Lateral boundary fields, including salinity, potential temperature and horizontal velocity, were relaxed to a climatology calculated from the monthly fields from the Estimating Circulation and Climate of the Ocean, Phase II synthesis (ECCO2) for the period 1992-2013 (Wunsch et al., 2009). It is important to note that salinity values used in the model are on the Practical Salinity Scale (PSS78) and are dimensionless. The total run time of the model simulation was 33 years for each simulation. This 33 year run includes a spinup phase of 30 years to reach equilibrium using a repeating loop of the climatology forcing. A climatology of the last 3 years of the run are used for the analyses.

14 P5, L18: “piled up” is a very vague statement, it’s possible to be much more exacting. As showed by Massom et al. (2010, JGR Oceans), the very thick fast ice immediately east of the MGT was thermodynamically thickened, and not “piled up” at all. Or are you referring to the largely dynamically-thickened fast ice (which probably was “piled up”) east of the pre-2010 grounded position of B09B (see Fraser et al., 2012, Journal of Climate)? I’m not sure which you’re referring to, because you state “piled up to the east of the glacier tongue”. Do you mean immediately east? Or farther afield?

Response: We understand the point the reviewer makes here, and have changed the wording accordingly. We are discussing the geographical source of the sea ice, as opposed to the mechanism by which it built up.

15 P5, L20-21: Figure 1D shows very similar salinities in 2008 vs 2011 though.

Response We thank the reviewer for this comment, but respond that the profiles of the salinities in 2008 and 2011 differ markedly. For example, at 200 m, in 2008 the salinity was 35.48, whilst in 2011 it was 34.43, a significant difference.

16 P6, L7 vs L21. The comment is made in L7 that the post-grounding water column is saltier than pre-calving, based on observations. However, in L21 you say that the postgrounding water column is fresher, based on model results. This is also manifested in Fig 1A vs Fig 2C. No mention of this discrepancy is made in the text of this paper. It seems like a major failure of the model to reproduce the observations. Could you make a comment about this?

Response: We acknowledge that this difference has not been fully explored in our original manuscript therefore in our updated manuscript we add the following text to section 3.2:

The numerical simulations pre- and post-calving indicate a change in oceanographic conditions in the area of the B09B iceberg, demonstrating the development of a polynya area in the lee of B09B post-calving. The modelled sea-ice production (Tamura et al 2016) within the Mertz Glacier polynya decreases and is restricted to an area closer to the coast. On the other hand, sea-ice production in the lee of the B09B iceberg post-calving is shown to increase markedly (Figures 2A and B).

The modelled ocean circulation for December shows that pre-calving, a westward coastal current carried water masses from the Mertz polynya and Commonwealth Bay areas towards the Commonwealth Bay NW XCTD positions (red squares on Figures 2A and B), forming a stratified water column with warm and fresh surface water (Figure 2C). The cold and salty water mass simulated pre-calving at the NW Commonwealth Bay XCTD positions is advected from the Mertz polynya and Commonwealth Bay post-calving. Modelled water column stratification is stronger in winter when there is sea-ice production. The model simulates a relatively warm layer at around 150 m depth (-1.18 ĚŽC) in July pre calving (Figure 2D). From 250 m to the ocean floor there is a cold

(-1.92 ËŽC) and salty (34.67) water mass that originates from the advection of HSSW from the Mertz polynya and Commonwealth Bay.

Post calving, the coastal current is blocked by the B09B iceberg, associated with a decrease in sea ice production within the Mertz polynya; little HSSW is advected into the area of the Commonwealth Bay NW XCTDs. The model average for December shows a stratified water column in summer, due to the advection from the north of a relatively warm water mass in summer. However, the water column post calving at the Commonwealth Bay NW XCTDs is entirely homogeneous in potential temperature (-1.90 ËŽC) and salinity (34.54), illustrating an active polynya that locally produces HSSW capable of being convected to the sea floor in winter. The model does not simulate an increase in salinity post-calving, but the seasonality illustrates the potential of a polynya developing in the lee of the B09B iceberg to locally form HSSW dense enough to sink to the sea floor, as inferred from the trends in the summer observations. It should be noted that our model simulations do not show the current evolution of the impact of the calving, but rather simulate the ocean conditions for two stable ice geometries, before and after the Mertz calving, thus can not be directly inter-compared to our XCTD data. However, the trends indicated from our regional model simulations provide valuable insights into mechanisms driving the circulation changes triggered as a response to the grounding of B09B off Commonwealth Bay.

17 P7, L22: The blocking of the coastal current is a major result of the model, yet its importance is not emphasized anywhere in the discussion. Here might be a good place to include it.

Response: We thank the reviewer for highlighting this important model result, and on Page 6, Line 18, comment upon this and also in the discussion, Page 7, Line 11.

18 P8, L2: How does the sea ice production compare between your pre and postcalving years?

Response: We add further information of this to Page 8, Lines 14-16, supported by new panels on Figure 2 to show sea-ice production pre and post calving.

19 P8, L10: Is HSSW formed in this region able to go on to form AABW? A comment on the bathymetry in the region of the new polynya would be appropriate here.

Response: We have added discussion on the contribution of HSSW form this region to AABW formation to Page7, Lines 10 to 11, and also in the Supplementary Information.

20 Figure 1 is very poorly presented. There are numerous typos (Decmebr and Tounge). The font size varies wildly across the figure, much of the text is illegible. Both inset maps for Fig 1A are almost useless. The lower left one really suffers from not having a coastline drawn. Fig 1A needs much more annotation. What is continent? What is fast ice" What is pack ice? How does the date of acquisition of this image relate to the time of field observations? Fig 1A should be zoomed out a little to provide more context – we can't even see the "original" B09B grounding location or the full extent of the tongue. There is absolutely no representation of the icescape pre-calving! The caption is confusing in the way that it references the sub-figures (and doesn't even mention sub-figures E, F or G). The figure refers to both B9B and B09B.

Response: Figure 1 has been updated and reformatted in line with the reviewer's suggestions.

21 Figure 2 is very poorly presented. Summer and winter figures seem randomly placed. Wouldn't it be a good idea to arrange all "winter" figures on the left, and all "summer" figures on the right? And why does "Nov-Dec" appear before "Aug-Sep"? It's chronologically backward. Fig 2B has no label on the legend. This figure is completely illegible in print, and only slightly better online. There's a fundamental problem with the presentation of Figures 2A and 2B: since the pre-calving vectors are directly overplotted on the post-calving vectors, and there's no translucency, then it's impossible to assess if the underlying vector if the overlying vector completely obscures it. It's a terribly unreadable way to present two vector fields. At the very least, one series of vectors should be offset slightly. Possibly most importantly, the outline of B09B appears to bear

little resemblance to the shape of that in Fig 1. Why is the eastern end of B09B not tapered in the model domain? B09B is referred to as both "B09B" and "B09b" in the caption. Finally, the caption could use some revisions, English-wise – some strange sentences as well as some parenthesis nastiness.

Response: Figure 2 has been updated in our resubmission, with the panels now showing the simulated changes in vertically integrated velocity and cumulative sea ice production, together with the changes in salinity and temperatures in the model domain. The 'shape' of B09B is realistic in the scale of the model domain, but we acknowledge does not perfectly capture the shape of B09B in the Landsat image.

22 Figure S1 adds very little to this manuscript. It would be sufficient to say that the xctd matches the microcat values very closely (possibly give an RMS difference, or similar measure of agreement).

Response: The supplementary figures now include Figure S1, S2 and S3, which add important information. Figure S1 is kept in the supplement for completeness.

Furthermore, we have addressed each of the technical corrections highlighted by Reviewer One.

We thank the reviewers for their input and detailed comments. Dr Chris Fogwill on behalf of the co-authors.

Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2016-19, 2016.

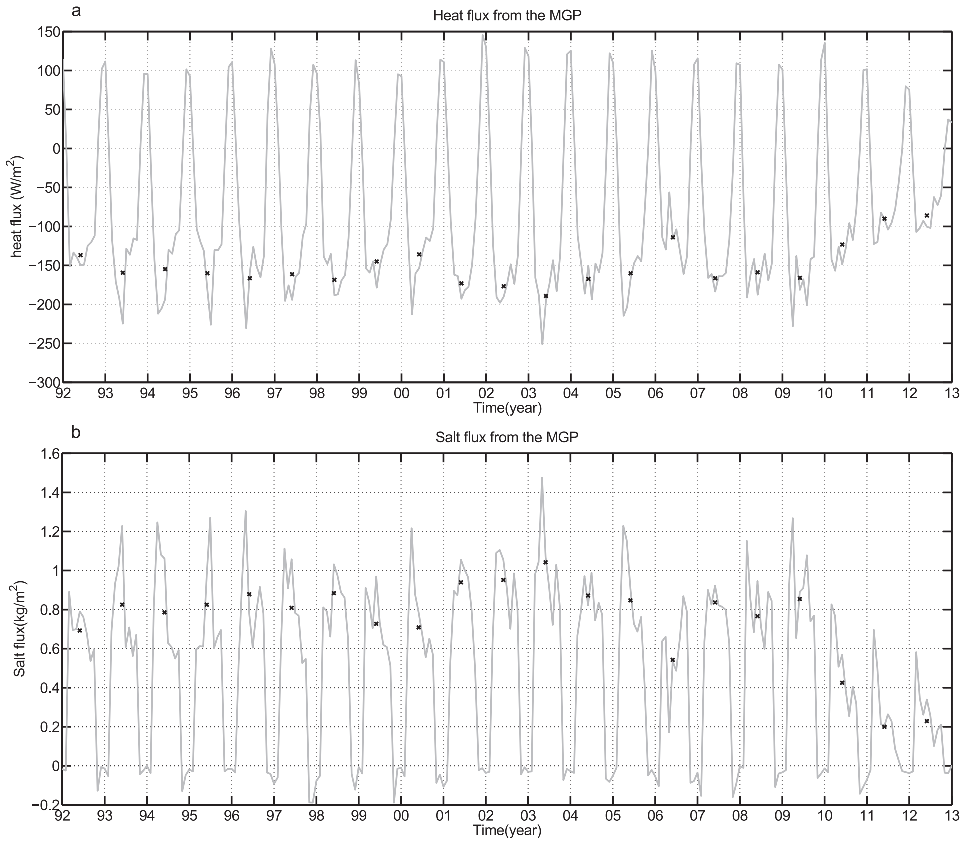

Fig. 1. . Monthly surface heat (a) and salt (b) fluxes averaged over the Mertz Glacier Polynya (MGP) from Tamura et al., (2016) data set, with winter time averages (May to September inclusive) shown with cros

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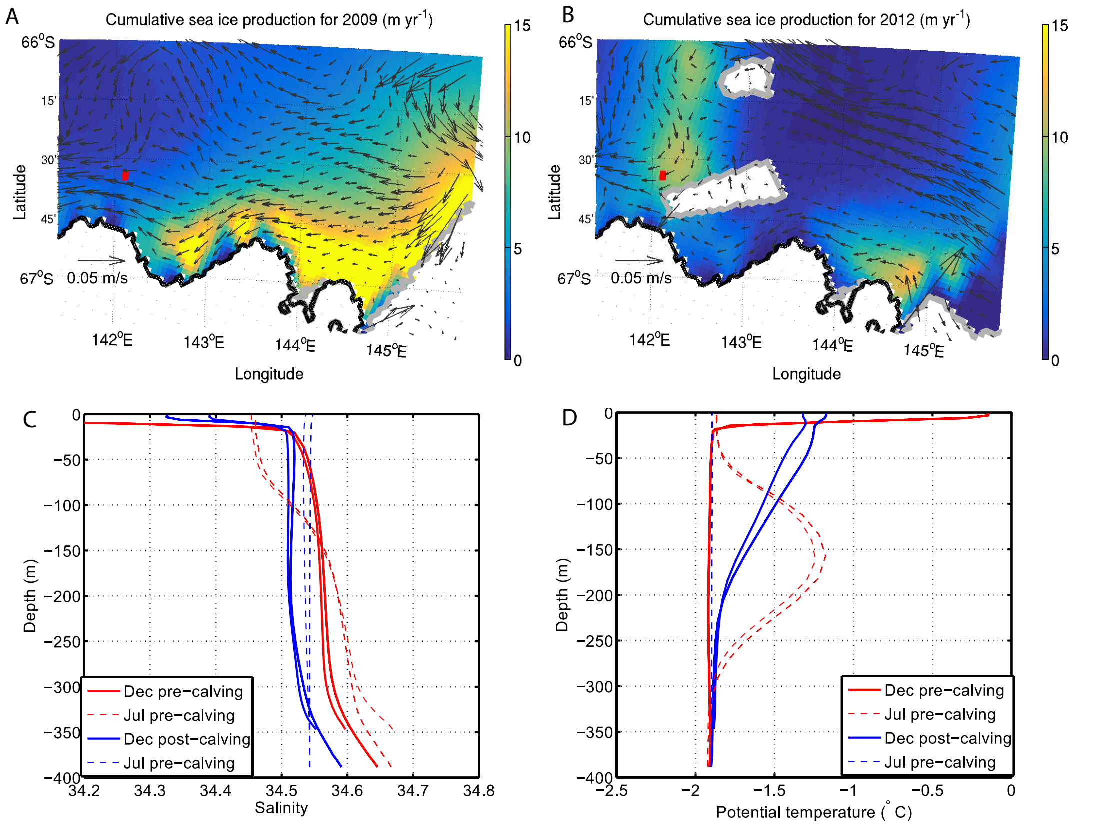

Fig. 2. Upper panels: Cumulative sea ice production (m/yr) for the two years of forcing for A pre- (2009) and B. post- (2012) calving simulations, overlaid with the vertically integrated horizontal velocity (